Experiments on Vortex-Excited Oscillations of Axially-Varying Cylindrical Structures In Non-Uniform Approach Flow

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LONG-TERM GOALS

The long-term goals of this experimental investigation are to identify and improve our understanding of the important fluid-structure interaction phenomena that occur during vortex-excited vibrations of axially-varying cylindrical structures in non-uniform flow fields.

OBJECTIVES

- To study the aerodynamic response of vortex-excited cantilevered uniform, tapered and wavy cylinders to uniform and linearly-varying shear flows.
- To investigate the wake and shedding characteristics of simulated non-responding wavy cables.
- To understand the vortex-dislocation structure in the near wake tapered cylinders and the role they play on the end cell induced vibration.
- To provide adequate data for analytical and computational modeling of the vortex shedding process for self-excited cylindrical structures as well as simulated sinuous cables.

APPROACH

The approach of the research is primarily experimental and is complemented by analysis and computations of wake-oscillator models performed at the University of Miami. The experimental approach utilizes a low-turbulence, indraft wind tunnel and the water tunnel at the Hessert Center for Aerospace Research at the University of Notre Dame. Flow about straight, tapered, and wavy cylinders are investigated to consider the effects of axially-varying body geometry. A hot-wire rake capable of measuring sixteen signals simultaneously is employed for measurements of mean and fluctuating velocities. Power spectral densities and the phase relationships are extracted from these signals to characterize the near-wake flow structure. Instantaneous displacement measurements of the cylinder amplitudes are made optically using a laser embedded in the model and a lateral effect detector. Flow visualization via smoke wire in the wind tunnel and Laser- Induced Fluorescence in the water tunnel is integrated to investigate the three-dimensional character of the body and fluid oscillations in the near wake as well as characterize the 2S and 2P mode flow structures.

WORK COMPLETED

During the past year numerous experiments were performed on freely oscillating cantilevered cylinders. New light mass straight and tapered cylinder models were tested in uniform and shear flows. Within the redesigned wind tunnel test section cantilevered cylindrical models were mounted by an aluminum leaf spring. The tests were performed in a lock-in range of 30 ft/sec to 50 ft/sec. The displacement range of the measurement system was greatly increased by a redesign of the optical system. Near-wake dynamics were surveyed simultaneously with the cylinder displacement using a 16-probe hot wire rake.

An effort was commenced to develop several new analysis techniques to identify and characterize cylinder wake structure. Techniques for identifying vortex dislocation events and relative phase using Hilbert and wavelet transforms are currently in progress.

In addition, new wavy cylinder models were fabricated for the purpose of simulating non-responding wavy cables. Some tests with the models of different wave length and wave steepness have been completed but further tests are in progress. Comparisons of the data with the results of the four models previously investigated are forthcoming.

RESULTS

Figure 1 shows a comparison between our uniform cylinder in uniform flow and the wake structure diagram of Williamson and Roshko (*Journal of Fluids and Structures*, 1988). The peak value of the amplitude occurs near the transition from the 2S shedding mode to the 2P mode. More specifically, this transition occurs near the curve denoted “I”, which corresponds to the regime where Bishop and Hassan (1964) observed a change in the amplitude of the fluctuating component of the drag forces on a circular cylinder.

Figure 2 shows “pseudo flow visualization” of the wake of a uniform cylinder in shear flow far from lock-in. This plot is generated using the time series data acquired simultaneously from 16 hot wire probes distributed spanwise in the wake. Exemplified in this plot is the vortex dislocation behavior of the wake. While there are times when structures shed relatively parallel to each other (as on the right and left extremes of the plot), oblique shedding occurs in regions near vortex dislocations. It can be seen from the middle portion of the plot that structures develop at an oblique angle and then a dislocation forms to accommodate the higher shedding frequency near the top of the cylinder (i.e. near the top of the plot).

Figure 3 contains a similar flow visualization plot of a tapered cylinder in uniform flow. In this case, the high frequency end of the cylinder (where the diameter reaches its minimum) is now at the bottom of the plot. It can be seen that the first two shedding cycles of the plot are relatively parallel, and then the third cycle begins a region of oblique shedding. By the fourth cycle there is a vortex dislocation to accommodate the higher shedding frequency near the bottom of the cylinder (i.e., near the bottom of the plot).

Analysis of data such as those in Figures 3 and 4 will be enhanced greatly with the techniques now in development (as discussed in the COMPLETED WORK section). Results of these efforts will be forthcoming.

In addition to the flow-induced vibration studies, flow visualization studies and wind tunnel measurements of a flow past simulated non-responding wavy cables have shown periodic spanwise wake structure. Introduction of mild waviness across the span of a cylindrical cable generates streamwise vorticity into the near wake flow. This vorticity forms longitudinal vortices which alternate in sign across the span and gives rise to a periodic variation in wake width. The cross flow stabilizes the near wake, suppresses regular Kármán vortex shedding and a significant drag reduction has been measured.

IMPACT/APPLICATIONS

The experimental results of the configurations tested are of a general nature and can be used to improve physical models that can predict unsteady lift and lock-in phenomena in many offshore systems. For large drag loads and possible vortex-induced vibration of offshore riser pipes, long slender tubular members, pilings, and underwater cables under tension it is feasible to introduce some form of three-dimensionality to weaken or suppress vortex shedding.

TRANSITIONS

We expect the results obtained from the present experiments to provide the necessary data for modelers to formulate more sophisticated wake-oscillator models.

RELATED PROJECTS

We are in close collaboration with the Division of Applied Marine Physics, University of Miami on their project “Modeling vortex-excited vibrations of axially varying cylindrical structures in non-uniform flow fields,” Principle Investigator: Richard A. Skop. Also, in cooperation with Professor Pratap Vanka of the University of Illinois, our water tunnel studies complement their recently completed direct numerical simulation of vortex shedding from a circular cylinder in a linear shear flow. Other program efforts related to this research are the numerical modeling efforts of flow-induced vibrations of cables by G. Karniadakis of Brown University and the computational efforts of A. Leonard of California Institute of Technology on flow induced vibration of a circular cylinder.

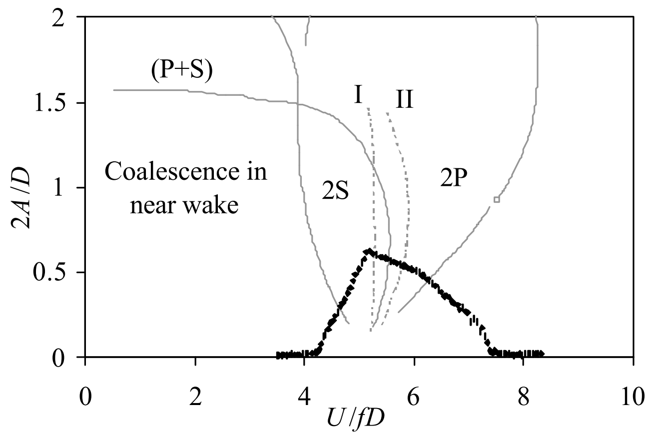
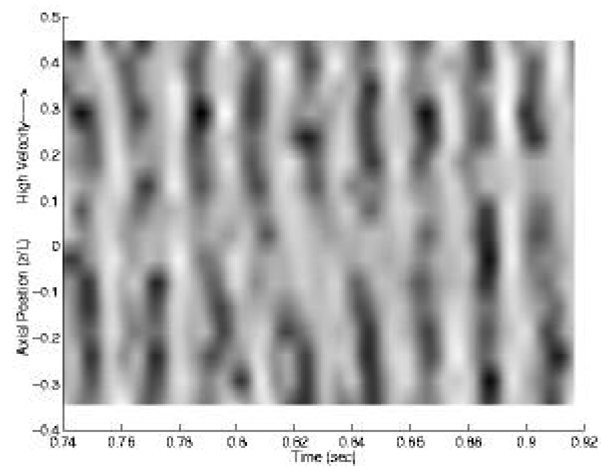


Figure 1. Amplitude data from uniform, cantilevered cylinder in uniform flow plotted with the shedding regime map of Williamson and Roshko (J. Fluids and Structures, 1988).

Figure 2 "Pseudo flow visualization" of the wake of a uniform cylinder in shear flow. High velocity end at top of plot.



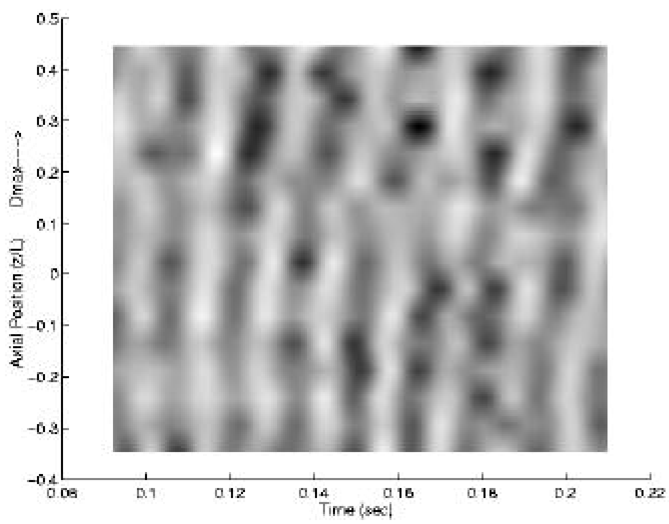


Figure 3 "Pseudo flow visualization" of the wake of a tapered cylinder in uniform flow. Maximum diameter end at top of plot. (Taper Ratio = 32:1).

PUBLICATIONS

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PATENTS

Intellectual Property Disclosure Form has been filed with the Office of Research at the University of Notre Dame titled “Use of Wavy Cylinder to Reduce Drag and Suppress Vortex-Induced-Vibration.”